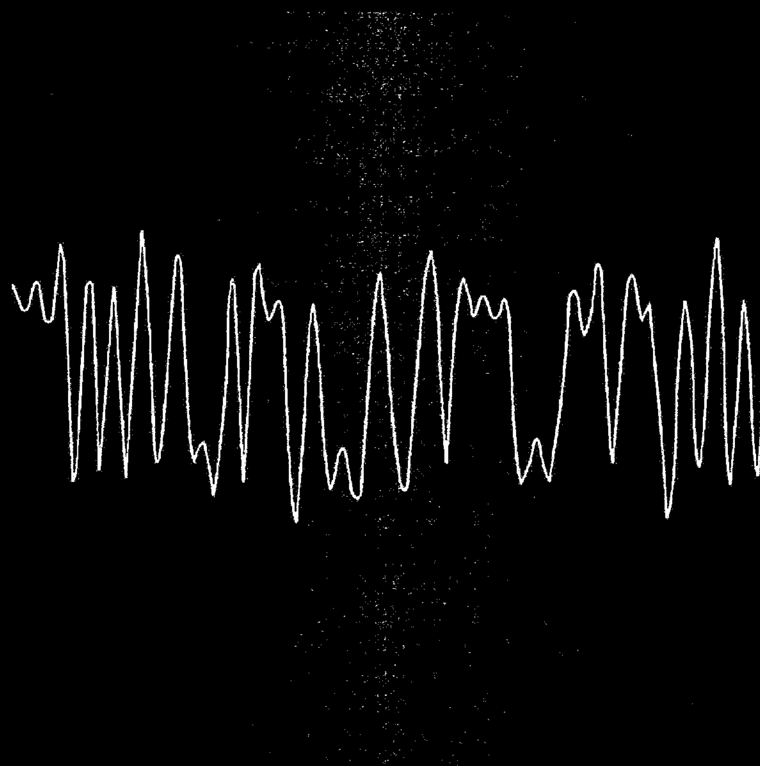
Exhibit A

MOBILE COMMUNICATIONS SERIES

CDMA Systems Engineering Handbook



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11.5 Implementation of Forward Link Dynamic Power Allocation

The control of transmitter power on the forward link of the IS-95 CDMA cellular system has been shown to be of great importance for the achievement of high user capacity. The common air interface standard IS-95 states [1] that the base station "may" enable forward link power control for traffic channels. This power control is an option that may or may not be employed. When this power control is enabled, the mobile station periodically reports frame error rate statistics to the base station. The base station may use the reported frame error rate statistics to adjust the transmit power of the forward traffic channel. In what follows, an approach is described for controlling all forward link channel powers through the effective gains implemented for individual channels in the base station equipment.

The solutions we have obtained for the optimal power allocation of the forward link Walsh channels were given in (11.24a) to (11.24d). We noted that the power for Walsh channel j is of the form

$$\mathrm{P}_j = \frac{\rho'_j}{(\mathrm{PG})_j}\,\nu, \quad \text{for Walsh channel } j \tag{11.43a}$$

where ν was given in (11.24e) to be

$$\nu\left(\rho'_{\text{pil}}, \rho'_{\text{sync}}, \rho'_{\text{pag}}, \rho'_{\text{traf}}\right) \triangleq \frac{N_m \mathrm{L}_T(R)}{1 - \mathrm{K}_{\mathrm{f}}\left(\rho'_{\text{pil}} + \dfrac{\rho'_{\text{sync}}}{(\mathrm{PG})_{\text{sync}}} + N_p \dfrac{\rho'_{\text{pag}}}{(\mathrm{PG})_{\text{pag}}} + \mathrm{K}_{\text{traf}}\, M \alpha_{\mathrm{f}} \dfrac{\rho'_{\text{traf}}}{(\mathrm{PG})_{\text{traf}}}\right)} \tag{11.43b}$$

It is clear that we can implement different gains for the Walsh channels by using baseband digital voltage gains

$$d_j = \sqrt{\rho'_j/(\mathrm{PG})_j}, \quad \text{Walsh channel } j \tag{11.43c}$$

and by using a power amplifier to implement the common gain that affects all the channels with a power gain proportional to

$$\text{Common power gain} = \nu\left(\rho'_{\text{pil}}, \rho'_{\text{sync}}, \rho'_{\text{pag}}, \rho'_{\text{traf}}\right) \tag{11.43d}$$

We now consider a numerical example to illustrate the principle of implementing optimal forward link channel powers. Let the system parameter values shown in Table 11.5 be assumed. The relative powers of the different channels may be controlled by giving each channel a different gain. This is most easily implemented at baseband, as the conceptual diagram in Figure 11.25 illustrates. The following Walsh channel relative digital gains are calculated for the nominal IS-95 parameter values as shown in Table 11.5:

$$
\begin{aligned}
d_1 &\triangleq \sqrt{\rho_1'/(\mathrm{PG})_1} = \sqrt{.0316/1} && = 0.1778 \text{ for the pilot channel} \\
d_2 &\triangleq \sqrt{\rho_2'/(\mathrm{PG})_2} = \sqrt{3.98/1024} && = 0.0624 \text{ for the sync channel} \\
d_3 &\triangleq \sqrt{\rho_3'/(\mathrm{PG})_3} = \sqrt{3.98/256} && = 0.1247 \text{ for each paging channel} \\
d_4 &\triangleq \sqrt{\rho_j'/(\mathrm{PG})_j} = \sqrt{5.01/128} && = 0.1979 \text{ for each traffic channel}
\end{aligned}
\tag{11.43e}
$$

where we assumed zero margin for simplicity ($\rho_j' = \rho_j$).

The diagram in Figure 11.25 shows how different gains for the Walsh channels achieves the objective of causing the channels to have different relative powers. To achieve the desired transmitter output power, there needs to be additional gain in the CDMA transmitter, denoted μ, at the RF power amplifier. Thus, there are the relative gains that are different for each channel, and there is a common gain that affects all the channels in the same way and causes the correct amount of output power to be delivered to the transmitter antenna.

Let R_{out} be the output load seen by the power amplifier, and let the power output for a particular Walsh channel be denoted P_j. The amount of common voltage gain that is needed is

Table 11.5 Assumed parameter values

Parameter	Value	Parameter	Value
Pilot $(E_c/\mathcal{N}_0)_{req}$	−15 dB	Receiver noise power	−105 dBm
Sync $(E_b/\mathcal{N}_0)_{req}$	6 dB	Base xmission losses	2 dB
Paging $(E_b/\mathcal{N}_0)_{req}$	6 dB	Mobile reception losses	3 dB
Traffic $(E_b/\mathcal{N}_0)_{req}$	7 dB	Voice activity factor	0.4
Base antenna gain	14.1 dBi	Power control factor	0.5
Mobile antenna gain	2.1 dBi	Interference factor	2.778

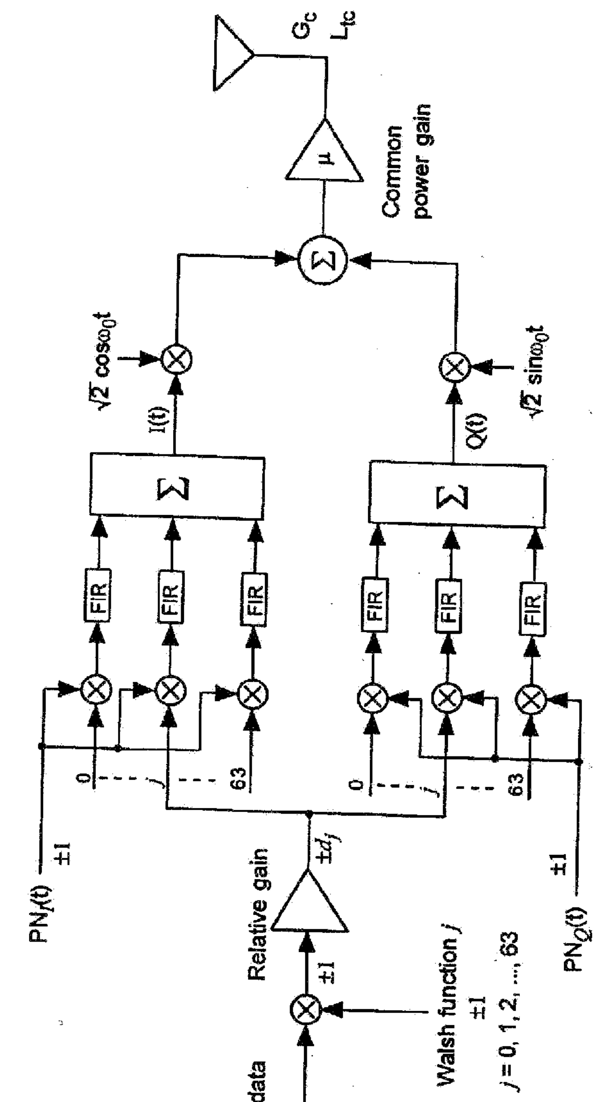

Figure 11.25 Dynamic forward link channel power control.

$$\text{Common voltage gain} = \sqrt{\mu} = \frac{\text{Desired channel output amplitude}}{\text{Relative channel amplitude} \times V} \tag{11.44a}$$

where $\pm V$ is the voltage corresponding to the baseband ± 1 logic values of the data. Since Power = (Amplitude)^2/Load, then

$$\text{Amplitude} = \sqrt{\text{Power} \times \text{Load}} \tag{11.44b}$$

and the desired channel output amplitude is

$$\text{Amplitude} = \sqrt{(\mathrm{P}_I + \mathrm{P}_Q) \times \mathrm{R}_{\text{out}}} = \sqrt{\mathrm{P}_j \times \mathrm{R}_{\text{out}}} \tag{11.44c}$$

where $\mathrm{P}_I = \frac{1}{2}\mathrm{P}_j$ and $\mathrm{P}_Q = \frac{1}{2}\mathrm{P}_j$ are the I-channel and Q-channel output powers and R_{out} is the amplifier load in ohms. For example, the ± 1 data logic may correspond to ± 3 volts ($V = 3$), and the impedance seen by the transmitter power amplifier output may be 50 ohms.

Thus, using Γ to denote the margin, assumed to be the same in each channel, and selecting any channel j to determine the needed gain, the needed output power gain is

$$\begin{aligned}
\text{Output power gain} = \mu &\triangleq \frac{\mathrm{P}_j}{(d_j \times V)^2/\mathrm{R}_{\text{out}}} \\
&= \frac{\rho_j \times \nu}{d_j \times V/\mathrm{R}_{\text{out}}} \\
&= \frac{\Gamma \cdot \nu\left(\rho'_{\text{pil}}, \rho'_{\text{sync}}, \rho'_{\text{pag}}, \rho'_{\text{traf}}\right)}{V^2/\mathrm{R}_{\text{out}}}
\end{aligned} \tag{11.44d}$$

In terms of the detailed parameters, the output power gain is given by

$$\begin{aligned}
\mu &= \frac{\Gamma\, N_m \mathrm{L}_T}{1 - \Gamma\,\mathrm{K}_{\mathrm{f}}\left(\rho_{\text{traf}} + \frac{\rho_{\text{sync}}}{1024} + N_p\,\frac{\rho_{\text{pag}}}{256} + \mathrm{K}_{\text{traf}} M \alpha_{\mathrm{f}}\,\frac{\rho_{\text{traf}}}{128}\right)} \cdot \frac{1}{V^2/\mathrm{R}_{\text{out}}} \\
&= \frac{\Gamma\, N_m\, \mathrm{L} \cdot \mathrm{L}_{\text{tc}} \cdot \mathrm{L}_{\text{rm}}/\mathrm{G}_{\mathrm{c}}\mathrm{G}_{\mathrm{m}}(V^2/\mathrm{R}_{\text{out}})}{1 - \Gamma\,\mathrm{K}_{\mathrm{f}}\left(\rho_{\text{traf}} + \frac{\rho_{\text{sync}}}{1024} + N_p\,\frac{\rho_{\text{pag}}}{256} + \mathrm{K}_{\text{traf}} M \alpha_{\mathrm{f}}\,\frac{\rho_{\text{traf}}}{128}\right)}
\end{aligned} \tag{11.44e}$$

For N_p and M varying, for $V^2/R_{out} = (3)^2/50 = 0.18\,\mathrm{W} = 180\,\mathrm{mW}$, and for the nominal system parameters presented previously:

$$\mu = \sqrt{\frac{\Gamma \cdot 10^{(-10.5+L(dB)/10+.2+.3-1.41-.21)}/180}{1 - \Gamma \cdot 2.778(0.0355 + N_p \cdot 0.0156 + 0.5 \cdot M \cdot 0.45 \cdot 0.0392)}}$$

$$= 10^{(L(dB)-138.8\,dB)/20} \sqrt{\frac{\Gamma}{1 - 2.778\,\Gamma(0.0355 + 0.01567 N_p + 0.00881 M)}} \tag{11.44f}$$

Properties of the multiplexed waveform. Recall from the orthogonal multiplexing example that was shown in Figures 5.5 and 5.6 that the Walsh function-multiplexed waveform has periodic peaks due to the agreement of the Walsh functions with each other in certain chip positions. To continue the numerical example used above, we show waveforms obtained from the superposition of differently weighted Walsh channels, and from observations of the waveforms we comment on requirements for CDMA infrastructure and test equipment. Suppose that the gains given in (11.43e) are used to simulate an IS-95 baseband data waveform comprised of the sum of 18 Walsh channels, as follows:

- Pilot signal with voltage gain 0.1778 and Walsh function H_0[7];
- Sync channel with voltage gain 0.0624 and Walsh function H_{32};
- Two active paging channels with voltage gains 0.1247 and Walsh functions H_1 and H_2;
- Two active traffic channels to mobiles at the edge, with voltage gains 0.1979 and Walsh functions H_8 and H_9;
- Four active traffic channels to mobiles at distances requiring half the power for a mobile at the cell edge, with voltage gains $0.1979/\sqrt{2} = 0.14$ and Walsh functions H_{10} to H_{13};
- Eight active traffic channels to mobiles at distances requiring one-fourth the power for a mobile at the cell edge, with voltage gains $0.1979/2 = 0.099$ and Walsh functions H_{14} to H_{21}.

[7] Here we use the H_i notation for the 64-chip Walsh functions, indexed as in IS-95. See Table 5.8 for a listing of these functions.

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sh functions, indexed as in IS-95.

In addition, for each pair of paging and traffic channels, we assume that one has an input data value of +1 (logic 0) and the other has an input data value of −1 (logic 1). Figure 11.26 shows the superposition of these weighted Walsh channels prior to combining with I- and Q-channel PN codes, FIR filtering, and modulation by sinusoidal carriers for forward link transmission. In anticipation of comparing this figure with the results of FIR filtering, a six-chip delay is included, as was included in Figures 1.50 and 1.53 to simulate the IS-95 FIR filter delay. Recall that the first chip in each 64-chip Walsh sequence has the same value. Therefore, since the pairs of paging and traffic channels cancel when their Walsh function values agree, the first (delayed) Walsh chip value is the sum of pilot and sync channel amplitudes, so that the first (delayed) value is $0.1778 + 0.0624 = 0.2402$. Thereafter, the total amplitude of the signal depends on the particular combination of Walsh function agreements and disagreements. If all the data-modulated Walsh chips had the same sign for some chip time, the total amplitude would equal

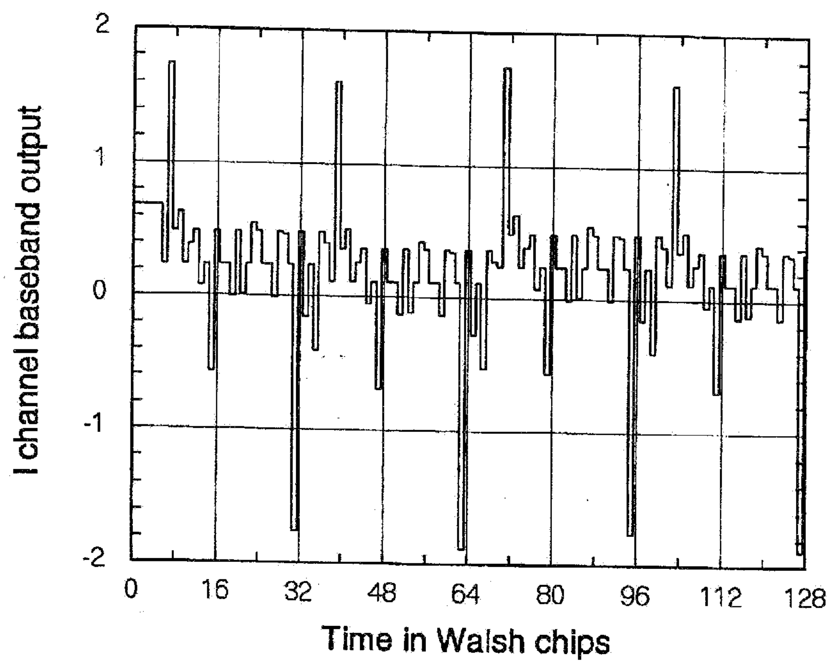

Figure 11.26 **Simulated Walsh-multiplexed combination of pilot, sync, paging, and traffic channels with different voltage gains.**

the sum of the gains of all the simulated channels, or ± 2.2374; we see from Figure 11.26 that the total amplitude for the particular Walsh functions that are used in this example varies between -1.85 and $+1.75$, and the amplitude waveform, in addition to having a period of 64 chips, is quite "peaky."

After the waveform of Figure 11.26 is separately combined with I- and Q-channel PN codes, and then is filtered and used to modulate cosine and sine carriers, the resulting envelope is the waveform shown in Figure 11.27. Note that the envelope waveform is characterized by relatively large peaks that occur periodically if the channel input data are held constant, as in this simulation. There are two practical implications of this characteristic behavior of the IS-95 forward link waveform. First, the forward link transmitter's power amplifier must have very good linearity in order to deliver the Walsh-multiplexed waveform without significant distortion. Second, it is obvious that the testing of such amplifiers using a channel simulator cannot be performed using bandlimited noise, even though the signal spectrum resembles that of bandlimited noise, because the envelope of the actual IS-95 time waveform does not resemble that of a noise waveform but has distinctive pulse-like features with a significantly large dynamic range.

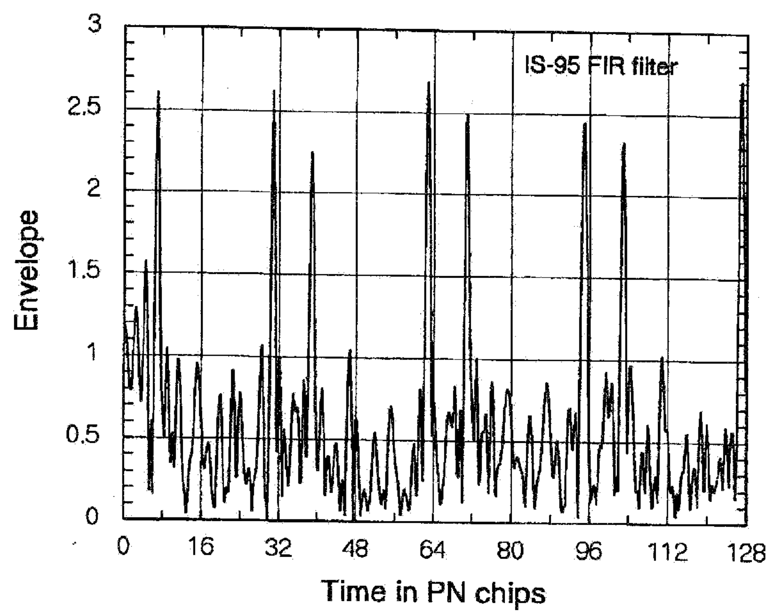

Figure 11.27 Envelope of simulated IS-95 signal.

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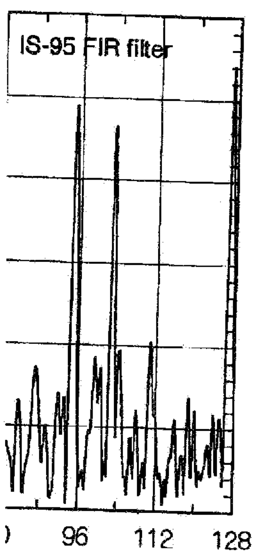

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Implementation of power allocation using measurements. The solution for forward link powers presented in Section 11.2 is based on modeling the total forward link power using the quantity K_{traf}, the forward link power control factor, to estimate the total traffic channel power in terms of the power needed to transmit to a mobile user at the edge of the cell. An alternative solution can be based on using a measurement of the actual total traffic power instead of that estimate. Under this approach, the equations to be solved, equations (11.18a) to (11.18e), are replaced by the following:

$$P_{total} = P_{pil} + P_{sync} + N_p P_{pag} + P_{tt} \leq P_{max} \tag{11.45a}$$

$$\left(\frac{E_c}{\mathcal{N}_{0,T}}\right)_{pilot} = \frac{(PG)_{pil}\, P_{pil}}{N_m L_T(R) + K_f P_{total}} \geq \rho_{pil} \tag{11.45b}$$

$$\left(\frac{E_b}{\mathcal{N}_{0,T}}\right)_{sync} = \frac{(PG)_{sync}\, P_{sync}}{N_m L_T(R) + K_f P_{total}} \geq \rho_{sync} \tag{11.45c}$$

$$\left(\frac{E_b}{\mathcal{N}_{0,T}}\right)_{pag} = \frac{(PG)_{pag}\, P_{pag}}{N_m L_T + K_f P_{total}} \geq \rho_{pag} \tag{11.45d}$$

where P_{tt} denotes the actual total traffic channel power on the forward link, assuming that this power is being controlled by the CDMA system on a per-user basis. Taking the case of equality for each of these equations, the corresponding joint solutions for the signaling (non-traffic) channels are

$$P_{pil} = \frac{(N_m L_T + K_f P_{tt})\, \rho_{pil}/(PG)_{pil}}{1 - K_f\left(\rho_{pil} + \dfrac{\rho_{sync}}{(PG)_{sync}} + N_p \dfrac{\rho_{pag}}{(PG)_{pag}}\right)} \tag{11.46a}$$

$$P_{sync} = \frac{(N_m L_T + K_f P_{tt})\, \rho_{sync}/(PG)_{sync}}{1 - K_f\left(\rho_{pil} + \dfrac{\rho_{sync}}{(PG)_{sync}} + N_p \dfrac{\rho_{pag}}{(PG)_{pag}}\right)} \tag{11.46b}$$

$$P_{pag} = \frac{(N_m L_T + K_f P_{tt})\, \rho_{pag}/(PG)_{pag}}{1 - K_f\left(\rho_{pil} + \dfrac{\rho_{sync}}{(PG)_{sync}} + N_p \dfrac{\rho_{pag}}{(PG)_{pag}}\right)} \tag{11.46c}$$

In this solution, the SNR requirements with margin (ρ'_{pil}, ρ'_{sync}, and ρ'_{pag}) may be used in place of the requirements with zero-margin. Note that the formulation does not result in a solution for traffic channel power, since it is assumed that the forward link power control is operative. If desired, however, we can calculate a value of traffic channel power for initializing the forward traffic power control loop by replacing ρ_{pag} and $(\text{PG})_{\text{pag}}$ in the numerator of (11.46c) with ρ_{traf} and $(\text{PG})_{\text{traf}}$, respectively.

Also, instead of estimating other-cell interference as K_{other} times the received forward link power at the cell edge, we can find the signaling channel powers using measurements or some other estimate of the term I_{other}, resulting in the pilot channel power solution (for example) given by

$$\text{P}_{\text{pil}} = \frac{\left[(N_m + I_{\text{other}}) \text{L}_T + \text{K}_{\text{same}} \text{P}_{\text{tt}} \right] \rho_{\text{pil}}}{1 - \text{K}_{\text{same}} \left(\rho_{\text{pil}} + \dfrac{\rho_{\text{sync}}}{(\text{PG})_{\text{sync}}} + N_p \dfrac{\rho_{\text{pag}}}{(\text{PG})_{\text{pag}}} \right)} \tag{11.47}$$

Note that, with or without these measurements, the solution for pilot power results in a value of the pilot power fraction ζ_{pil} that is not a fixed value but adapts to the amount of traffic and interference.

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